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Is there an uncanny valley of virtual animals? A quantitative and qualitative investigation

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ABSTRACT

Approaching a high degree of realism, android robots, and virtual humans may evoke uncomfortable feelings. Due to technologies that increase the realism of human replicas, this phenomenon, which is known as the *uncanny valley*, has been frequently highlighted in recent years by researchers from various fields. Although virtual animals play an important role in video games and entertainment, the question whether there is also an uncanny valley for virtual animals has been little investigated. This paper examines whether very realistic virtual pets tend to cause a similar aversion as humanlike characters. We conducted two empirical studies using cat renderings to investigate the effects of realism, stylization, and facial expressions of virtual cats on human perception. Through qualitative feedback, we gained deeper insight into the perception of realistic computer-generated animals. Our results indicate that depicting virtual animal-like characters at realism levels used in current video games causes negative reactions just as the uncanny valley predicts for humanlike characters. We conclude design implication to avoid that sensation and suggest that virtual animals should either be given a completely natural or a stylized appearance. We propose to further examine the uncanny valley by the inclusion of artificial animals.

1. Introduction

In 1970, Mori observed negative emotional reactions of human observers towards very life-like robots and prostheses (Mori et al., 1970/2012). Mori assumed that adding humanlike attributes to robots generally causes people's emotional response to become more positive. However, past a certain point of human likeness, when a human entity appears almost–but not completely–real, it suddenly evokes uncomfortable feelings in human observers. Mori called the sudden dip in that relation between human likeness and acceptance of people the *uncanny valley*, which is illustrated in Fig. 1. Mori also noted that motion or physical contact increases the effect. He mentioned zombies and puppets as examples to explain the concept of the uncanny valley. Today, it is commonly assumed, that the uncanny valley also occurs in video games and computer-animated movies (Kätsyri et al., 2016; MacDorman et al., 2009; Schneider et al., 2007; Tinwell et al., 2010).

Today, the uncanny valley by Mori is an actively discussed topic in research on human-computer interaction (HCI) (Brenton et al., 2005; Burleigh et al., 2013; Cafaro et al., 2014; MacDorman, 2005a), human-robot interaction (HRI), video games (Schneider et al., 2007; Tinwell et al., 2010), animated movies (Kätsyri et al., 2016), neuroscience (Cheetham et al., 2011), psychology (Cheetham and Jancke, 2013), and philosophy (Misselhorn, 2009). Although a "stuffed animal" is mentioned in Mori's graph, non-human artificial characters have been insufficiently taken into account by empirical research. The uncanny valley has mainly been investigated using humanlike characters and on dimensions of human likeness. Thus, it remains unclear whether effects or design implications of the uncanny valley can be transferred from humanlike to animal-like virtual characters or robots.

Due to their symbolic and allegorical character, designers, storytellers, and engineers often prefer animal characters instead of humans. Artificial animals are frequently used in entertainment and advertising as well as for therapeutic and educational purposes (Kidd et al., 2006). Beside the positive effects of using artificial animals, there are also reports of negative experiences with virtual or stuffed animals. Noteworthy examples of negative responses are critiques of the computer-generated cat *Azrael* in the movie *The Smurfs*. One feature of Azrael is that the cat expresses itself using human emotions and behaves humanly. Burr from the Boston Globe calls that cat a "creepy animal CGI" (Burr, 2011). Duralde from The Wrap, in reviewing *The Smurfs 2* movie,

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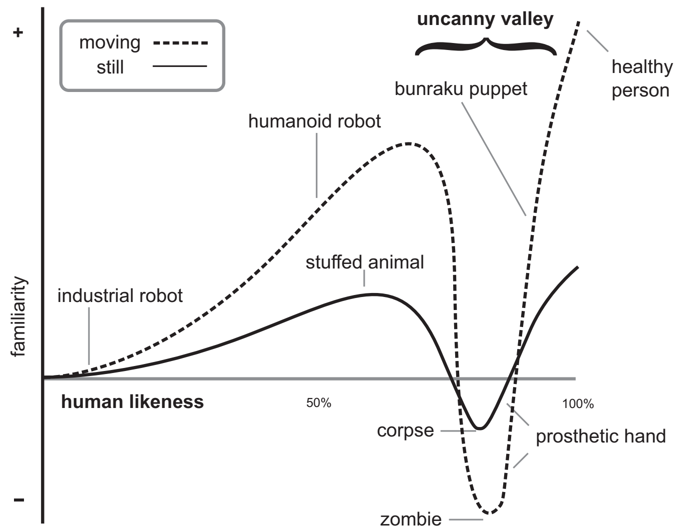


Fig. 1. Simplified version of Mori's original graph. Modified illustration by MacDorman (2005a).

states that *Azrael* "never feels like a real feline; turns out there's an uncanny valley for animals, too" (Duralde, 2013). In art and literature, reactions to stuffed and composed animals, for example through taxidermy, were also associated with uncanny sensations (cf. Gutierrez, 2009; Powell, 2004).

The question whether realistic artificial depictions of animals can fall into an uncanny valley is important because it would have a significant impact on research investigating that phenomenon. A hypothetical "uncanny valley of animals" would either mean that Mori's dimension of human likeness is not only related to humans and has to be enhanced or that the phenomenon appears in a different shape (or not at all). However, there is currently no empirical investigation of Mori's hypothesis, which explicitly considers an uncanny valley of virtual animals or discusses how and whether animals should be incorporated into the uncanny valley hypothesis.

In this paper, we therefore investigate whether the uncanny valley is applicable to *virtual* animals. We aim to answer the following research questions: (1) Can findings of the uncanny valley be transferred from humanlike to animal-like virtual characters? (2) Which factors potentially cause unpleasant effects for virtual animals? (3) Which design implications result from these findings? Research found that using computer-generated characters the uncanny valley appears between intermediate and high levels of virtual realism and using atypical entity feature, which indicates there are potentially two kinds of uncanny valleys (Cheetham and Jancke, 2013; Cheetham et al., 2013; 2011; Gray and Wegner, 2012; Kätsyri et al., 2015; Looser and Wheatley, 2010; MacDorman et al., 2009; Mitchell et al., 2011; Moore, 2012; Seyama and Nagayama, 2007). We hypothesize that both aspects can exist for human observations of non-human computer-generated characters (virtual animals) and operationalize the effect as lower familiarity ratings.

- H1. A virtual animal rendered at high levels of realism is perceived less familiar than using photo-realism or stylization.
- H2. At high levels of photo-realism atypical virtual animal features decrease familiarity more than at lower levels of photo-realism.

Furthermore, it is important to understand which factors trigger potentially unpleasant effects using virtual animals. By contrasting these findings with previous work for humanlike characters we are able to extend our knowledge of existing frameworks that try to explain the uncanny valley or potentially allow the development of a new overarching framework which considers humans *and* animals.

In this paper, we present the results of two studies to gain deeper insights into the human perception of virtual animals. First, we investigate the effect of different levels of realism on the perception of virtual animals and analyze qualitative feedback provided by our participants in an online survey. The second study examines the effects of stylization and anthropomorphic emotions using virtual animals. Our results indicate that the phenomenon of the uncanny valley may apply to virtual animals, particularly of intermediate graphics level as currently used in video games. We contribute design principles for avoiding the effect using realistic animal characters and recommend to consider virtual animals for a better understanding of the uncanny valley.

2. Related work

In the following, we discuss previous work that highlights the importance of animal characters in video games and HCI. Afterward, we discuss previous work on the uncanny valley related to video games and animals.

2.1. Virtual animals in video games & HCI

Based on a survey of game magazines from 1988 to 2005, Miller and Summer report that over the years, animals have been the main character of up to 14.6% (from 1991 to '93) of all video games (Miller and Summers, 2009). Furthermore, animals have been the most prominent enemy in up to 36% (from 1994 to '96) of all surveyed games (Miller and Summers, 2009). Virtual animals are used as companions in educational technology. Chen et al. (2007), for example, purposely selected an animal as the main character whose traits and behaviors are governed by the student's learning profile. Similarly, Hswen et al. (2013) purposely chose a virtual animal for their game that aims to teach children healthy behavior. The authors' choice was motivated by a survey of commercially successful mobile applications and the assumption that virtual animals do not exclude anyone by race or ethnicity.

Dormann et al. state that the value of animal companionship in enhancing social competencies and psychological well-being is widely acknowledged (Dormann et al., 2013). As shown by Chen et al., virtual animal companions can support active self-reflection and learning in the affective and social domains (Chen et al., 2005). The importance of life-like animals is widely acknowledged in therapy of phobias using VR applications as they are used, for example, in the treatment of spider phobia as by Garcia-Palacios et al. (2002). Wrzesien et al. generally discussed the potential impact of using virtual reality (VR) and augmented reality (AR) technologies in therapies of phobia of small animals (Wrzesien et al., 2015).

Previous work in HCI also explores the usage of virtual pets in particular. Ruckenstein, for example, suggests using virtual pets to encourage children to become more mobile in general (Ruckenstein, 2010). Altschuler recommends using virtual pets to increase appreciation in autistic children for their theory of mind and thinking of others (Altschuler, 2008). Chen et al. propose using virtual animals to encourage students to promote effort-making learning behaviors (Chen et al., 2011).

2.2. The uncanny valley in virtual environments

First evidences of the uncanny valley in video games for human characters were found by Schneider et al. based on a paper by Duffy (2003); Schneider et al. (2007). They investigated subjective ratings of participants towards images of game characters and found hints of a non-linear relationship in video games as proposed by Mori et al. (1970/2012). Researchers identified specific influences and derived guidelines for character designers. For example, Tinwell et al. showed that facial expressions and human emotions change the perception of virtual characters (Tinwell et al., 2011). Their design guidelines suggest that designers should pay attention to animations of upper facial expression especially when trying to display fear and sadness. They found that articulation and lip movement during speech influence the effect of the uncanny valley (Tinwell et al., 2014). Similarly, Mäkäräinen et al. showed that exaggerated facial expressions of very realistic human depiction led to the uncanny valley (Mäkäräinen et al., 2014).

Hanson suggests that aesthetics can help to overcome the uncanny valley (Hanson, 2006). MacDorman et al. found that ideal facial proportions and smooth skin may help to avoid uncanny effects (MacDorman et al., 2009). This was supported by findings by Schwind et al. (2015). The authors found preferred characteristics of user created avatar faces and suggest that an average 3D face with a youthful appearance results in higher acceptance compared with faces that strongly violate the human average.

2.3. Animals and the uncanny valley

Previous work focuses on the relationship between familiarity (or eeriness) and the dimension of human likeness; however, this does not explicitly state that the uncanny valley must have a dimension of human likeness.

A study by MacDorman and Chattopadhyay was conducted to determine whether *reducing realism consistency* in visual features increases the uncanny valley (MacDorman and Chattopadhyay, 2016). Using transitions among features of realistic and computer-generated entities, they showed that inconsistencies among features increased the eeriness for humans and animals (using bird and dog), however, not for objects. Corresponding to Mori's idea the authors hypothesized that "the more anthropomorphic the entity, the more reduced consistency in feature realism increases the uncanny valley effect" (MacDorman and Chattopadhyay, 2016). However, they found that inconsistencies between real and computer-generated eyes, eyelashes, and mouth increased the perceived eeriness significantly less for humans than for animal entities, which could be different if more realistic animal models would have been used.

Furthermore, Yamada et al. showed that difficulties in categorizing humanlike faces resulted in a negative overall impression (Yamada et al., 2013). They attributed their results due to the *categorization-based stranger avoidance* as well as the cause of eerie feelings in difficulties in categorizing an entity into a novel category, which theoretically could also be applicable to animals. They were critized by MacDorman and Chattopadhyay (2016) due to artifacts in the used stimuli. In a discussions paper, Kawabe et al. argued that the results are still consistent with the theory of categorization-based stranger avoidance (Kawabe et al., 2016). Furthermore, they conclude that the uncanny valley "can be extended to dimensions not directly related to human" even when Mori described it in a non-human to human continuum (Kawabe et al., 2016; Mori et al., 1970/2012). A study by Bartneck et al. used a robot toy (iCat) to investigate how users perceive synthetic emotional facial expressions (Bartneck et al., 2004). Their study indicates that emotional expressions of anthropomorphic entities are perceived categorically. In a response on this paper, MacDorman and Chattopadhyay (2017) stated that this explanation is doubtful, for example, because "eeriness is seldom felt when meeting strangers".

Ferrey et al. found trends depicting the uncanny valley that occurred for all continua including non-human stimuli and are hence not only related to humans (Ferrey et al., 2015). However, they used hybrid morph continua including humanlike as well as animal-like faces to trigger unpleasant effects. Kawabe et al. mentioned that the eeriness occurring between different animal categories as used in the study by Ferrey et al. is out of scope by the *realism inconsistency hypothesis* but could be well explained by the categorization-based stranger avoidance theory (Ferrey et al., 2015; Kawabe et al., 2016; MacDorman and Chattopadhyay, 2017). It remains unclear, whether this kind of eeriness as used by Ferrey et al. can be attributed to the humanlike or to the animal-like part.

Ramey concludes that the repulsion of uncanny depictions increases if the potentially applicable category of an observed character falls into the same category as the observer (Ramey, 2005). This may lead to the assumption that there is a weaker uncanny effect on the perception of animal-likeness compared with human likeness. Empirical evidence on explanations for the uncanny valley was summarized by Kätsyri et al. in a meta-review of previous work considering the uncanny valley (Kätsyri et al., 2015). They found support in previous work for the *perceptual mismatch* hypothesis, which predicts that humans are more sensitive and less tolerant to deviations from typical norms when judging human faces (Kätsyri et al., 2015). However, they argue that the uncanny valley "is manifested only under specific conditions" and "that inconsistent levels of realism and atypical features represent different conditions leading to the uncanny valley" (Kätsyri et al., 2015).

Reactions produced by artificial representations of realistic animals have been insufficiently considered so far. However, dead animals provoke similar emotions as the uncanny valley: disgust, revulsion, and fear (D'Zurilla et al., 1973). Reasons for the uncanny valley were associated with an innate fear of death and a subconscious strategy of coping with death's inevitability (MacDorman, 2005b). There are also similar descriptions of ambivalent and uncomfortable feelings associated with dead animal bodies (cf. D'Zurilla et al., 1973; MacDorman, 2005b). *Animal Reminder* is one of three kinds of disgust described by Olatunji et al. (2008). MacDorman and Entezari found Animal Reminder sensitivity is "confusing" but increases eerie ratings (MacDorman and Entezari, 2015). Steckenfinger et al. conducted an eye-tracking study with monkeys using computer-generated renderings of monkeys and assume an evolutionary mechanism behind the uncanny valley (Steckenfinger and Ghazanfar, 2009).

2.4. Measuring the uncanny valley

One measurement instrument to detect the subjective perception of humans towards robots is the so called Godspeed questionnaire proposed by Bartneck et al. (2008). The questionnaire is primarily designed for surveys in human-robot interaction. Special requirements in terms of the uncanny valley led to an improved alternative developed by Ho and MacDorman (2010). The questionnaire measures the subjective perception of people and has been successfully validated for robots and for virtual humans (MacDorman et al., 2013; Mitchell et al., 2011). To control the scale of human likeness, Cheetham and Janke introduce linear blendings (morph continua) of CGI and photos to represent the dimension of human likeness (DHL) (Cheetham and Jancke, 2013). Such blendings should reduce inconsistent findings when collecting subjective ratings of humanlike stimuli. However, Kätsyri et al. pointed out that the use of morph continua (e.g., as used by Cheetham and Jancke, 2013; Cheetham et al., 2013; MacDorman, 2006; MacDorman and Chattopadhyay, 2016) between two images may produce blending artifacts. In this case, it can not be precluded that the artifacts, not the categorical mismatch of the stimuli, cause negative responses (Kätsyri et al., 2015).

2.5. Summary

Previous work highlights the importance of virtual animals in games and in HCI (Chen et al., 2011; Hswen et al., 2013; Miller and Summers, 2009). Research of the uncanny valley investigates the effect of human likeness using robots and virtual characters (MacDorman, 2005a; MacDorman et al., 2009; Ramey, 2005; Tinwell et al., 2011). Studies used animal stimuli as subject of their investigations (Ferrey et al., 2015; MacDorman and Chattopadhyay, 2016; Steckenfinger and Ghazanfar, 2009). Little is known about the potential existence of an uncanny valley for virtual animals. Measuring the effect is currently only established using questionnaires that are explicitly related to human likeness (Bartneck et al., 2008; MacDorman et al., 2013; Mitchell et al., 2011). An increased effect using motion as predicted by Mori could not be confirmed by previous work (Mori et al., 1970/2012; Piwek et al., 2014; Thompson et al., 2010). Previous research also used human-animal hybrids to investigate the uncanny valley (Ferrey et al., 2015). In line with Ferrey et al. and

Kawabe et al., we aim to deepen the understanding of eeriness in virtual animal perception (Ferrey et al., 2015; Kawabe et al., 2016).

3. Method

Related work indicates that inconsistent levels of realism as well as atypical features separately cause the uncanny valley phenomenon. In particular, Kätsyri et al. pointed out that there are possibly two different "valleys" (Kätsyri et al., 2015). Therefore, we collected data about the subjective perception of humans towards virtual animals at different levels of realism as well as by adding unnatural features. We decided to use computer-generated renderings (instead of linear blendings) of animals because they are well suited for controlling different degrees of realism.

Revealing the effect for one kind of animal is sufficient to determine whether the uncanny valley is applicable to at least one non-human species. This does not necessarily mean that there is the same effect for every kind of non-human virtual character or that the uncanny valley is generally applicable to virtual animals at all. Because the uncanny valley is related to familiarity, we assume that a potential effect of the uncanny valley on virtual animals rather occurs when an animal is familiar. Pets are familiar to humans, and cats are the most kept pets in many countries (e.g., in the U.S., U.K., and Germany[1]). Cats are used in video games and in HCI related research (Zanbaka et al., 2006). Inspired by the importance of cats in humans' everyday life, we assume that virtual cats are significant for many application domains, such as video games and health therapies. Thus, the following studies focus only on cats. We do not consider dogs, for example, due to the large physiological differences between breeds, which potentially lead to perceptual biases in humans. Effects using other animals are not investigated in the study.

We designed two studies using cat renderings as stimuli: In a first study, we collected quantitative measurements of the perceived eeriness towards renderings of virtual cats from high to low levels of realism. Supplementary, we collected qualitative feedback to gain deeper insights about the attitude of our participants towards virtual cats in current video games. As the related work shows, very realistic humanlike faces with artificially enlarged eyes, facial expressions, and exaggeration of emotions (MacDorman et al., 2009; Mäkäräinen et al., 2014; Seyama and Nagayama, 2007; Tinwell et al., 2011) cause very negative reactions. Thus, in a second study, we investigated these aspects using effects of atypically enlarged eyes and emotions on virtual cat renderings. To collect reliable data from a large sample, both studies were conducted using online surveys.

4. Study I: Realism and eeriness of a virtual cat

In the first study, we aim to gain insights into humans' perception of virtual animals. Using a familiar pet species, namely cats, we aim to collect quantitative as well as qualitative feedback from a number of participants.

4.1. Study design

The study is divided into a quantitative and a qualitative survey part. The quantitative part of the study follows a repeated measures (RM) design with realism level as the only independent variable. We used the perceived realism, eeriness, and aesthetic quality as dependent variables. In the qualitative part of the survey, we asked participants to provide feedback about their impression of four virtual animals from current video games and real-time applications.

4.2. Measures

Previous work investigated the effect of the uncanny valley using questionnaires that are explicitly related to human likeness. Therefore, we developed a new questionnaire based on some items from the successor of the Godspeed questionnaire introduced by Bartneck et al. (2008); Ho and MacDorman (2010). Because perceived *human likeness* and *attractiveness* are highly related to anthropomorphic (humanlike) properties, we decided to replace these items by *naturalness* and *aesthetics*, respectively. Two semantic differentials are retained to evaluate the perceived similarity towards a real animal: *artificial-natural* and *synthetic-real*. Two further semantic differentials ask for *familiarity: uncanny-familiar* and *freaky-numbing*. The last two semantic differentials are adopted to evaluate *aesthetic* aspects: *ugly-beautiful* and *unaesthetic-aesthetic*. All items were rated on a 7-point Likert-scale. We operationalize familiarity ratings as measure to test the hypotheses.

4.3. Stimuli

We opted to use renderings of a short-haired cat in a neutral pose. To avoid prejudices caused by white or black furred cats, we chose a gray-haired cat (Russian Blue) without using any prominent fur pattern. However, fur does not allow linear morph continua as used by Cheetham et al. and Ferrey et al. (Cheetham and Jancke, 2013; Ferrey et al., 2015). Therefore, we developed seven virtual cat models with a gradually increased level of realism. All images (R1-8, depicted in Table 1) are based on a reference photo (R1).

The reference photo shows a gray short-hair Russian Blue cat sitting in a neutral pose without disturbing artifacts or distracting background. We decided to use this image because the scene setup is neutrally arranged and the whole scene is easy to reconstruct in 3D. Textures and models were created in Autodesk Mudbox by a professional CG artist. Cat, background, area lights, and camera were reconstructed in Autodesk Maya. All 3D images (R2-7) were rendered using global illumination and ambient occlusion. Fur of the high-quality (HQ) model (R2) was created using hair geometry with the XGen-Tools for Maya. The cat model in image R2 has 134,256 triangles. The following image (R3) was rendered using a simplified and noise-free hair model. Hair geometry was removed and polygons were reduced for the next two images (R4, 16,782 triangles and R5, 8390 triangles) corresponding to levels of realism used in current video games. The model as well as the texture quality of the ultra low-poly model (R6, 424 triangles) were further reduced to an ultimate minimum as used in games for very low levels of details. The model of the second to last image (R7) received a hand-painted texture and toon-look using Cel-shading. The render size corresponds to the original resolution of the reference image (2456 × 2718 pixels). The last image (R8) was manually vectorized in Adobe Illustrator 6 with simplified contours in black and white. All images show the same cat in the same pose using different levels of realism. Using these stimuli, we assume that we are able to transfer the paradigms from computer-generated humans to computer-generated animals.

For the second part of the study, we took in-game screenshots of the three video games *Grand Theft Auto V, The Witcher III - Heart of Stone, The Sims III* as stimuli. The images are shown in Fig. 2. These video games were selected based on their topicality and dissemination. An additional image is a rendering of a commercially available real-time 3D model, which was downloaded from an online store for 3D Models (turbosquid.com). All screenshots were captured using lossless quality settings and were cropped to an image size of 500 × 400 pixels. No image was scaled.

4.4. Survey procedure

Participants obtained a link to our survey website. They were asked to maximize their browser and received information about the procedure. After collecting demographic data about gender, age, pet owner-

[1] Pet statistics from the year 2014: http://www.petsecure.com.au and http://www.statista.com , last date of access: April 4th, 2016.

Table 1
Stimuli of the first survey: The first image (R1) is the reference photo (by kuba_girl / Shutterstock.com). R2-7 are rendered in 3D. R2 contains complex fur geometry, R3 contains simplified fur. R4 and R5 are textured cat models as they are used in video games. R5 contains no subdivisions. R6 shows a more simplified facet model without textures. R7 was rendered in toon style. R8 is a contour enhanced vectorization without colorization.

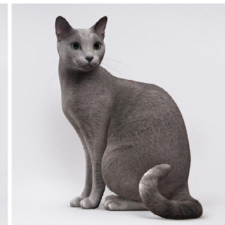
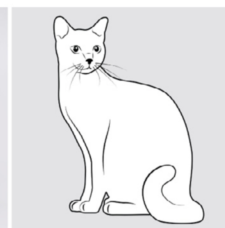
			
R1: Reference Photo	R2: HQ 3D Model w. Realistic Fur	R3: HQ 3D Model w. Simple Fur	R4: HQ 3D Model w/o. Fur
			
R5: Low Poly 3D Model	R6: Ultra Low Poly 3D Model	R7: Toon Model w. Painted Texture	R8: Vector Style 2D Model

Fig. 2. Virtual cats from recent video games and real-time application: *Grand Theft Auto V* (left, top), Nibbles from *The Witcher III - Heart of Stone* (right, top), standard model of a Russian Blue Cat from *The Sims III + Pets Expansion Pack* (left, bottom), commercially available low-poly cat from turbosquid.com (right, bottom).

ship, and home country, the first stimulus was presented in full-screen within the browser. Clicking on an image reduced its size to 30% and revealed the rating scales. A participant could only proceed when all questions were completed. By clicking again, the image size could be increased back to full-screen. The rating scales consist of the six word pairs based on the bipolar scales in terms of realism, familiarity, and aesthetics. The scales were randomly sorted and oriented to avoid biases. The eight stimuli were presented in random order.

After finishing the first part of the study, the participants were asked to provide comments about the virtual cats of current real-time applications (see Fig. 2. Participants were asked to answer the following questions in separate input fields: *Describe in your own words your personal impression about the depiction of the cat above. Please give reasons for your impression. Are there features that particularly attract your attention?* The participants could continue without leaving a comment. Finally, participants could leave their e-mail address to take part in a draw for a gift card. The mean survey completion time was 12.5 min ($SD = 10.1$).

4.5. Participants

We recruited participants via Facebook, Twitter, online forums, and mailing lists of two universities in Germany. In total, 339 people from age 15 to 76 ($M = 24.7, SD = 6.6$) completed the study. The sample includes 152 males (44.8%), 186 females (54.9%), and 1 other/not specified (0.3%). Home countries of the participants corresponded to the demographics of our university's undergraduate population (93.8% from the german-speaking area, 6.2% foreign or unclassified). 93 participants (31.78%) stated that they currently own at least one cat as a pet. 76 additional participants (22.41%) pointed out that they had at least one cat as a pet in the past. This means that 169, almost half of all participants (49.8%), have ever had a cat in their life.

4.6. Quantitative results

To assess the reliability of the three measures we conducted a Spearman–Brown correlation analysis, which is considered as the most reliable estimate for two-item scales (Eisinga et al., 2013). The correlation matrix shows that items within realism ($\rho = 0.836, p < 0.001$), familiarity ($\rho = 0.715, p < 0.001$), and aesthetics ($\rho = 0.830, p < 0.001$) have the highest correlations among the measures (all others with: $\rho \leq 0.709, p < 0.001$).

We conducted a repeated measure (RM) one-way multivariate analysis of variance (MANOVA). Using Wilks' lambda, there was a significant effect of stimuli realism on our three measures, $\Lambda = 0.062, F(21, 318) = 227.703, p < 0.001, \eta^2 = 0.399$. Separate univariate analyses of variance (ANOVAs) on the dependent variables revealed significant effects on familiarity, $F(7, 2366) = 284.738, p < 0.001$), perceived realism, $F(7, 2366) = 722.195, p < 0.001$), and aesthetics, $F(7, 2366) = 226.235, p <$

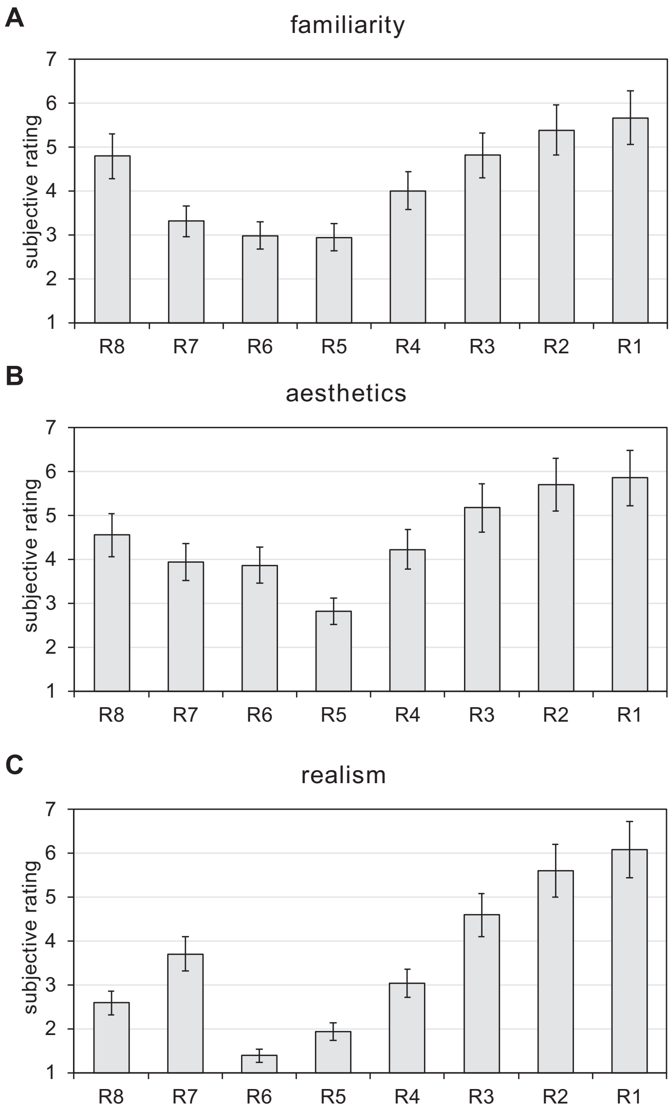


Fig. 3. Mean subjective ratings of perceived familiarity (A), aesthetics (B), and realism (C) of the eight stimuli in our realism continuum ranging from R1 (real) to R8 (abstract). Error bars show the 95% confidence interval (CI95). All means statistically differ from each other ($p < .05$), *except* the values visually connected by the horizontal lines.

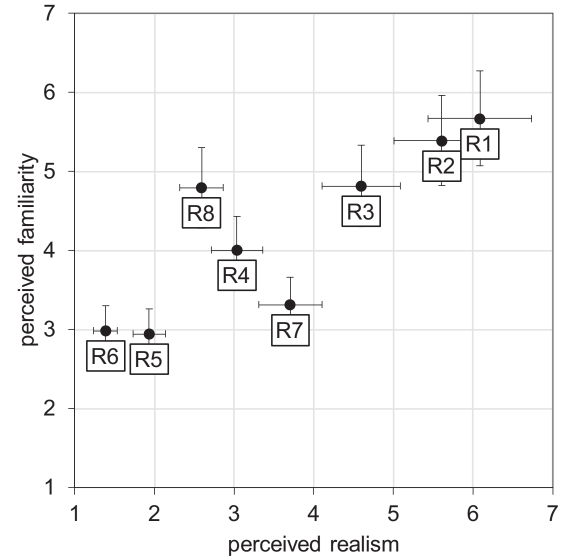


Fig. 4. Subjective perception of realism related to familiarity of the stimuli R1 (Real) to R8 (Abstract). Error bars show the 95% confidence interval (CI95).

0.001. Fig. 3 shows the results of the three measures collected in the first part of the study.

Bonferroni corrected pair-wise t-tests revealed significant differences between all conditions ($p < 0.05$) except between R3–R8 ($p = 1.000$), and R5–R6 ($p = 1.000$) for ratings of familiarity and between R1–R2 ($p = 0.375$), R4–R6 ($p = 0.056$), R4–R7 ($p = 0.309$), and R6–R7 ($p = 1.000$) for ratings of aesthetics. All pair-wise comparisons of perceived realism were significant (with all $p \leq 0.002$). From the stimuli R1 ($M = 5.674, SD = 1.176$) to R5 ($M = 2.948, SD = 1.265$), we found a significant decline of the subjectively perceived familiarity. From R6 ($M = 2.988, SD = 1.282$) to R8 ($M = 4.798, SD = 1.270$) the results indicated an ascent of familiarity again. The mean ratings of R5, R6, and R7 are below the neutral average of 4.0. The subjectively perceived aesthetics decreases from R1 ($M = 5.856, SD = 1.095$) to R5 ($M = 2.827, SD = 1.285$) and increases again from R6 ($M = 3.870, SD = 1.663$) to R8 ($M = 4.556, SD = 1.330$). As mean ratings of familiarity, mean ratings of aesthetics are below the neutral average of 4.0 for R5, R6, and R7. Measurements of the subjectively perceived realism decrease from R1 ($M = 6.087, SD = 1.143$) to R6 ($M = 1.933, SD = 1.030$) and increase with R7 ($M = 3.706, SD = 1.152$) and R8 ($M = 2.591, SD = 1.448$).

The results of the study depend on the order of the eight stimuli. The stimuli represent a constructed continuum from most realistic (R1) to least realistic (R8) computer-generated renderings. Using this order, the results seem to shape a “valley” of familiarity. However, Fig. 4 shows the familiarity ratings related to the assessments of realism. Through reordering the stimuli based on the respondents' assessments of realism the position of R7 moves to between R3 and R4, the position of R8 moves to between R4 and R5.

As previously mentioned, almost half of all participants ($N = 169, 49.8\%$) have had a cat in their life. Participants who stated to currently have or ever had at least one cat as a pet in the past were summarized as cat owners. Moreover, there was a balanced number of male and female participants. Potential effects of both factors were investigated by conducting a RM-MANOVA including cat ownership and gender as between-subjects variable. We found significant effects of gender, $\Lambda = 0.973, F(3, 333) = 3.048, p = 0.029$, and cat ownership, $\Lambda = 0.966, F(3, 333) = 3.894, p = 0.009$, and no interaction of both factors, $\Lambda = 0.979, F(3, 333) = 2.400, p = 0.068$, however, and interaction of gender with realism $\Lambda = 0.899, F(21, 315) = 1.687, p = 0.031$. Through separate univariate ANOVAs, we found significant effects of gender on perceived familiarity, $F(1, 335) = 5.064, p = 0.025$, significant effects of cat ownership on familiarity, $F(1, 335) = 6.061, p = 0.014$ as well as on aesthetics, $F(1, 335) = 4.873, p = 0.028$, (all others with $p \geq 0.566$). We found significant interaction effects of gender × realism on eeriness, $F(7, 2345) = 3.373, p = 0.001$, and aesthetics, $F(7, 2345) = 2.842, p = 0.006$, not on perceived realism, $F(7, 2345) = 1.759, p = 0.247$. The tests revealed that familiarity was rated significantly higher by men ($M = 4.330, SE = 0.051$) than by women ($M = 4.174, SE = 0.046$), however, it depends on the degree of realism. Female participants showed lower familiarity ratings at lower degrees of realism. Cat owners' perceived familiarity was significantly higher ($M = 4.337, SE = 0.049$) than for participants who never had a cat ($M = 4.167, SE = 0.049$). Aesthetics ratings were significantly higher for cat owners ($M = 4.619, SE = 0.052$) than for participants who never had a cat ($M = 4.431, SE = 0.011$).

4.7. Qualitative results

Participants provided 786 comments in total–199 about the cat from Grand Theft Auto V (in the following labeled as GTA5), 195 about the cat from The Witcher III: Heart of Stone (WITCHER3), 186 about the cat from The Sims III + Pets Expansion Pack (SIMS3), and 206 about the commercially available model from turbosquid.com (TS). Participants were asked to describe their personal impression about the depiction. They were also asked, which features especially attract their attention. All comments were analyzed and coded. Two researchers went through all transcribed notes to check each other's coding and to establish consistency in the assignment of codes to the same phenomena. With open coding, the first iteration of Grounded Theory, three main categories of perception in virtual animals were found: animal-likeness, mostly scene related aesthetic qualities, and facial as well as body expressions.

4.7.1. Naturalness of the cat

The first category is a mental comparison with the *naturalness* of a real animal. Previous knowledge of what an animal has to look like may lead to a perceptual mismatch while regarding an animal that does not look completely natural. Ambiguity, missing, or incorrect attributes may lead to a negative impression of a virtual animal depiction. To describe the lack of naturalness, participants often use other animals (or even objects) to describe their impression. *"Seems like a stiff plastic toy. The fur does not look fluffy and the eye glance is too strong"* (SIMS3); *"The cat does not look like a cat–more like a hyena, because of the short, curved back".* (TS); *"The cat looks more like a panther [...]. In general, the colors are too intense to be considered realistic".* (SIMS3); *"The cat has legs like a dog [...] or the body of a wild cat.". "Looks rather like a rat".* (GTA5). *"Looks like a robot. Artificially, can not really rate it".* (SIMS3). *"The cat looks a bit like a dog"* (SIMS3); *"The cat looks like a mummy".* (TS); *"Scary, because the cat looks more like a mutant".* (TS); *"The object is more similar to a raccoon than to a cat.* (GTA5). Also missing features that make the comparison with a natural cat difficult were considered negative by the participants: *"Missing fur makes the 'fluffiness' and thus the very likeable aspect of cats disappear".* (SIMS3); *"No whiskers. Ears are a bit too long. Hair is missing. Looks more like the physique of a dog. Face of the cat is ugly".* (TS).

4.7.2. Aesthetic qualities and relation to the scene

A negative impression might be reinforced by the lack of aesthetic qualities which were often brought into connection with the scene. Therefore, we summarized aesthetic qualitities and how the cat fits into the scene in a single category. These aspects are also influenced by properties of the environment and are related to how the animal fits into the scene. One example is the lack of shadows, which gives the impression the cat is levitating: *"Cat levitates in the air. [...] Dead eyes and ears look like they are clipped out. Although quite realistic, but also quite unaesthetic".* (TS). *"Good lighting, but missing details. Shadow isn't correct. Cat seems to levitate".*(WITCHER3). *"Posture and missing fuzz from the fur make it look less realistic".*(WITCHER3). *"The cat could be more realistic. Looks like it is pasted into the image. The size of the cat in relation to the environment bothers me".* (GTA5). *"The cat looks like it is cut out and glued on"* (GTA5). *"The dark shadow makes the cat look creepy. It also acts vigorously and pugnacious. Certainly in this case the environment plays an important role".* (WITCHER3); Furthermore, the overall look of a cat depiction was considered negatively: *"The cat's appearance is stylized rather than realistic. Textures and colors seem slightly exaggerated".* (SIMS3). *"The patterning makes it look real. The eyes are not bad. The uncanny part comes as you combine this realistic looking texturing with a low res model".* (SIMS3).

4.7.3. Health status and body language

Participants commented uncertainty about the cats' health status or their body language. This also includes facial expressions, angry eyes, and aggressive body postures. We found that the participants inspect the cat depiction carefully to see if it could be a threat or a disease carrier. We summarized these comments into one category because of their relation to an evolutionarily related explanation (contact avoidance due to uncertainties). Considering rabies where the infected animal is aggressive and attack without provocation both health status and body language pose a threat: *"The cat looks as if it has a bad disease".* (TS); *"The cat looks scary, because I cannot understand what its body and facial expressions really mean".* (TS); *"Cat in aggressive posture, nasty facial expression"* (GTA5); *"Cat has an aggressive attitude, the facial expression looks uncomfortable".* (WITCHER3); *"Looks like a statue, because the attitude is very symmetrical and unnatural".* (SIMS3); *"The facial expression is too rigid, the body very voluminous. Therefore, the cat looks a little bit scary to me".* (GTA5); *"The fur looks very good, good posture, attitude, and snout. Only the eyes are scary".* (WITCHER3); *"Facial expression looks artificial because of the forehead".*(WITCHER3). In particular, the appearance of the eyes were mentioned and emphasized in contrast to other body parts: *"Evil eyes. Belligerent".* (GTA5); *"The eyes of the cat look scary. Otherwise, the body is well done".*(WITCHER3).

4.7.4. Summary

When a virtual depiction contradicts the familiar concept of an animal, a negative impression arises. We consequently derive the following triggers for the violation of a familiar virtual animal depiction: Mistakes in natural appearance, unaesthetic aspects of the animal within a scene, and a threatening or rigid body as well as facial expressions. Only when these attributes are considered positive, willingness for interaction arises. *"No realistic proportions and the face is uncanny. Thus, this cat is not cuddly"* (TS). Furthermore, people feel threatened by concerns about the health status or body language. Avoiding direct contact with an animal whose condition is not clear-minded or friendly may have an evolutionary purpose.

Some comments point to certain expectations or habituation towards computer game graphics. *"The cat reminds me of a computer game"* (TS). Interestingly, the virtual cats are dated much older, than the game from which they originate. The oldest video game from our selection is from 2011 (Sims III) *"Reminds me of old games like Tomb Raider or Sims I"* (SIMS3). *"Looks like 10-year-old computer game graphics"* (WITCHER3). *"A bad computer cat out of the 90s"* (SIMS3). *"I get nostalgic about old computer games"* (SIMS3). *"Asset from the 80s?"* (TS). This means that virtual animals may trigger a perceptual shift to older game graphics although the game is more recent.

4.8. Discussion

In the first study, we collected quantitative ratings as well as qualitative feedback. In the first part of the study, we used a reference photo and seven computer-generated images with a varying degree of realism to measure the perceived familiarity of a virtual cat. High levels of realism were assessed to be very familiar. Lowest ratings for familiarity were measured for realism levels as used in current video games (see R5 and R6). Stylized and unrealistic levels of a virtual cat received higher ratings of familiarity (R7 and R8) again. Thus, we found a decrease of familiarity using cat depictions at intermediate graphic levels of realism, which results in a long U-shaped valley (see Fig. 3). This is predicted by Mori's hypothesis of the uncanny valley and was verified for virtual humanlike characters (MacDorman et al., 2009; Mori et al., 1970/2012; Tinwell et al., 2011).

The shape of the valley would differ if the stimuli were sorted by realism ratings of the participants. Fig. 4 shows R1-6 in an almost linear relation among familiarity and realism, while stimuli R7-8 are not part of this relationship. The manipulation of realism could be compromised due to the following reasons: (1) The concept of realism is partially biased by other associations; and (2) stylized or abstract images might not belong to the same continuum of realism. The kind of stimuli changed from realistic (R1-6) to another perceptual construct (R7-8) which is finally considered as non-real anymore. Thus, the results can not clearly confirm H1. We assume that the same problem of using one single continuum of realism exists for both humanlike as well as animal-like characters. Reducing the degree of realism by adding abstraction does not consequentially mean to map points on the same continuum. However, this does not explicitly contradict Mori's hypothesis, that brought multiple categories ("industrial robot", "stuffed animal", "zombie") into a related continuum ("human likeness"). We will later discuss, how difficulties of categorical perception can be integrated into the theory of the uncanny valley of animals. Further problems with the dimension of human likeness and the usage of gradual continua (such as artifacts) are discussed by Kätsyri et al. (2015).

Furthermore, the results show that the virtual cat at intermediate (R4-5) and not at high photo-realistic levels of realism (R5-7) are rated less familiar than the photo (R1), toon painting (R7), or the simplified vector illustration (R8). Instead of a sudden decrease of familiarity, the familiarity ratings rather show a downhill slope between R1 and R6. This could be potentially caused by a shift of familiarity, due to a higher sensitivity towards the own (and more familiar species). This was not supported by our results as perceived familiarity due to cat ownership was not significantly affected. Furthermore, using a very large set of robot faces Mathur and Reichling (2016) found that the deepest point of the valley can potentially found at very intermediate and not at very intermediate high levels of human likeness as Mori predicted (Mathur and Reichling, 2016; Mori et al., 1970/2012). Therefore, we suggest that future work should directly compare human and animal entities to investigate this shift.

Results of the first part of the survey show significant differences of the perceived realism between all stimuli. This means that the reference photo (R1) and the computer-generated rendering with the highest level of virtual realism (R2) can still be distinguished from each other. However, ratings of familiarity and aesthetics of a high-level advanced computer-generated imagery (CGI) model (R2) do not significantly differ from the reference photo. Therefore, we assume that virtual animals can be rendered at realism levels where they receive high acceptance. This is confirmed by the current trend of movies using very realistic computer-animated animals. However, advanced rendering and post-processing techniques, as used in animated movies, are currently not applicable to animals in video games, which indicate that they are currently affected by the uncanny valley. The uncanny valley hypothesis, however, predicts that *almost* realistic characters fall into the valley. Therefore, it needs to be discussed, *where* the uncanny valley is in animals. In particular, R6 has low realism scores; however, is clearly not close to the real cat. This suggests that R6 is potentially on the left or "safe" side in Mori's graph. Higher ratings of familiarity and aesthetics of cat owners and no interaction effects reveal that having at least one cat as a pet generally improves the participants' attitude towards the cat depictions. However, we found no enhancement of the amplitudes (lower ratings at lower degrees of realism, higher ratings and higher degrees of realism), which could have indicated that familiarity increases the perceptual sensitivity towards an animal entity.

Qualitative results show that the graphical standard of current computer games may lead to an uncanny perception of animals. Comments regarding current animals in real-time environments indicate, in addition to an individuals' attitude towards animals, three different factors to be responsible for an eerie sensation: This includes the naturalness of an animal model, its expression, and its aesthetic qualities which are strongly influenced by the scene environment (e.g., lights). We found that people seem to be confused and rated virtual cats negatively when they perceived the depiction as ambiguous. Negative responses due to violations of the expectation regarding an animal's outward appearance would support the perceptual mismatch hypothesis (Cheetham and Jancke, 2013; Yamada et al., 2013).

We therefore assume, in respect to games, that when a player pays attention to other aspects of the game (scene, story, etc.), the visual quality of the rest of the scene may cover the potentially eerie appearance of an animal. However, if a virtual animal with a slightly abnormal appearance or unusual expression of face and body is in the focus of a game's scene, its depiction may leave a negative impression. Qualitative feedback also reveals that participants were partially reminded of older video games and older graphical standards. We assume that there are effects of habituation or expectation that may have an influence on the perception of virtual depictions. These aspects could also have an influence on the uncanny valley.

5. Study II: Effects of stylization and emotions

5.1. Study design

The qualitative part of the first study indicates that unusual expressions and an exaggerated appearance may increase eerie effects of a virtual animal. These aspects were not considered in the first study. The related work shows that very realistic human faces with atypical features such as artificially enlarged eyes cause very negative reactions (MacDorman et al., 2009; Seyama and Nagayama, 2007). Two further studies showed that facial expressions and exaggeration of emotions cause larger effects if the face was more humanlike (Mäkäräinen et al., 2014; Tinwell et al., 2011). We used anthropomorphic emotions due to their frequent usage in current animated movies as in *The Smurfs I* (2011) or *The Jungle Book* (2016). Anthropomorphic emotions as well as artificially enlarged eyes are atypical features of cats which are further investigated using different levels of rendering in the second study. Thus, we aim to investigate and determine whether and how atypical properties can be transferred to virtual cat renderings.

We reduced the number of realism levels to reduce the overall number of possible conditions. We decided to only use four levels of realism, namely R1, R2, R4, and R5 from the first study. Realism level of R3 was excluded due to only minor structural changes of the cats' fur in regard to R2. Abstraction or abstract-like levels of realism as used in R6, R7, and R8 were excluded as well to model a single continuum of the cat's realism (R1-R4). In addition to the general neutral style of the cat, we added atypical features through enlarging the eye size and gave the cat a stylized appearance. Facial changes express three states of emotion: neutral, happy, and sad.

Thus, for the second study, we used 4 levels of realism, 2 levels of stylization, and 3 levels of emotions in a multi-factorial within-subject design. We used the same measures of familiarity, realism, and aesthetics as introduced in the first study.

5.2. Stimuli

A matrix of 24 stimuli based on the cat depiction from the first study (see Table 1) was created. Four levels of realism were combined with 2 levels of stylization and 3 levels of emotions resulting in these 24 conditions (close-ups of all stimuli see Table 2). The cat got a stylized appearance through enlarging the eye size (140%) and two contrary emotions (happy and sad). The 3D models used in the first study were morphed and rendered again. The photo reference was manipulated using Adobe Photoshop.

5.3. Survey procedure

Participants obtained a link to our survey, where they received information about the survey and the terms of use. After collecting demographic data about gender, age, and game as well as video usage, the stimuli were presented. As in the first study, participants rated each image using six word pairs on a bipolar seven-point scale in terms of realism, familiarity, and aesthetics. All corresponding adjectives were randomly sorted to avoid biases. Orientation, as well as the order of the scales, were randomized and placed after each image. The order of images was randomized as well. An image change, which was initiated by clicking on the next-button, appeared with a delay of two seconds to avoid direct comparisons. The average time to complete the survey was 33.1 min ($SD = 28.33$).

Table 2
Close-ups of the image changes of the virtual cat used in the second study. 4 levels of realism (R1-R4) were combined with 3 levels of emotions and 2 levels of stylization which results in 24 different conditions.

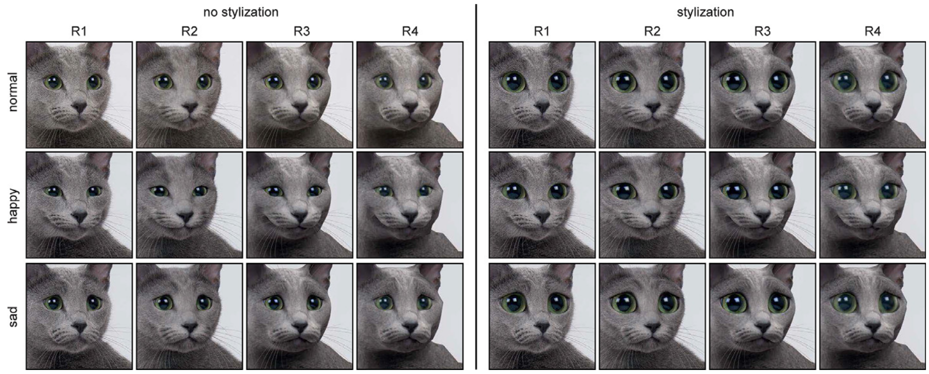


Table 3
Main and interaction effects of three repeated-measure ANOVAs.

Factor	df	error	Realism F	Familiarity F	Aesthetics F
R	3	639	612.049 *	230.363 *	430.828 *
S	1	213	668.104 *	320.292 *	291.392 *
E	2	426	212.792 *	182.055 *	160.927 *
R*S	3	639	163.471 *	52.062 *	53.806 *
R*E	6	1278	27.232 *	13.022 *	12.785 *
S*E	2	426	135.614 *	113.325 *	80.656 *
R*S*E	6	1278	24.090 *	8.581 *	5.651 *

R = Realism (error df = 639); S = Stylization (error df = 213); E = Emotion (error df = 426),
* for all: $p < .001$,

5.4. Participants

Participants of the second online survey were also recruited via Facebook, forums, and mailing lists of our two universities in Germany. In total, 214 participants, 91 males (42.5%), 121 females (56.5%), and 2 other/not specified (0.9%) took part in the second study. Participants age ranged from 18 to 44 ($M = 23.29, SD = 3.77$). Home countries of the participants reflected the demographics of our university's undergraduate population (92.5% from the german-speaking area, 7.5% foreign or unclassified). 68 participants (31.78%) stated that they currently have at least one cat as a pet, 49 additional (22.90%) participants pointed out that they had at least one cat as a pet in the past. This means that 117 participants (54.67%) have had a cat as a pet in their lifetime.

5.5. Results

As in the first study, the reliability of the three measures was assessed using Spearman-Brown correlation analysis. The correlation matrix shows that items within realism ($\rho = 0.822, p < 0.001$), familiarity ($\rho = 0.728, p < 0.001$), and aesthetics ($\rho = 0.789, p < 0.001$) have the highest correlation among other items (all others with $\rho \leq 0.713, p < 0.001$).

A $4 \times 2 \times 3$ RM-MANOVA was significant for realism, $\Lambda = 0.156, F(9, 205) = 123.052, p < 0.001, \eta^2 = .844$ stylization, $\Lambda = 0.238, F(3, 211) = 224.834, p < 0.001, \eta^2 = 0.762$, and emotion, $\Lambda = 0.283, F(6, 208) = 87.658, p < 0.001, \eta^2 = 0.717$. There were significant interaction effects of realism $\times$ style, $\Lambda = 0.296, F(9, 205) = 54.165, p < 0.001, \eta^2 = 0.704$, realism $\times$ emotion, $\Lambda = 0.418, F(18, 196) = 15.187, p < 0.001, \eta^2 = 0.582$, style $\times$ emotion, $\Lambda = 0.420, F(6, 208) = 47.861, p < 0.001, \eta^2 = 0.580$, and realism $\times$ style $\times$ emotion, $\Lambda = 0.534, F(18, 196) = 9.483, p < 0.001, \eta^2 = 0.466$. Separate univariate ANOVAs for each dependent variable revealed significant effects as well as significant interactions of the three factors. The results of the factorial analysis are listed in Table 3. Similar to the first study, Bonferroni corrected pairwise comparisons between the levels of realism revealed significant differences ($p < 0.05$) except for the levels R1 and R2 for familiarity ($p = 0.984$) and aesthetics ($p = 0.666$). Post-hoc tests between all three emotional states revealed significant differences ($p < 0.001$).

We analyzed the familiarity ratings to understand a participant's affinity towards stylization and emotional expressions on virtual animals. As previously mentioned, post-hoc comparisons revealed significant differences between the total means of all three emotional states (with all $p < 0.001$). Fig. 5 shows that adding stylization using enlarged eyes as well as emotions strongly decreases the familiarity between all kinds of non-stylized depictions.

The unchanged reference photo was rated with the highest familiarity. Facial expressions as well as stylization negatively influence the perceived familiarity. We also found significant differences between all states of emotional expressions. In most of the conditions, except for the stylized photo reference of the cat, the sad expression was rated more familiar than the happy facial expression.

As presented in Table 3, interaction effects between emotions and stylization as well as between emotions and realism were confirmed (with both $p < 0.001$). No significant effects of cat ownership ($p \geq 0.132$) and no significant effects of gender were found ($p \geq 0.076$). There were no further significant interaction effects ($p \geq 0.119$), except for style $\times$ cat ownership, $\Lambda = 0.899, F(3, 101) = 3.778, p = 0.013$. No further effects of gender and cat ownership were found using univariate tests.

5.6. Discussion

The second study shows that two findings of uncanny valley research can be potentially transferred from humans to animals: We found significant interaction effects between all three factors: realism, atypical features, and emotion. Decreasing realism and atypical features (enlarged eyes) lead to significantly decreased familiarity ratings of a virtual animal from stimuli R1 to R4. As the related work shows, this is also the case using humans or humanlike characters (cf. MacDorman et al., 2009; Seyama and Nagayama, 2007). Through decreasing realism and adding anthropomorphic facial expressions on a virtual animal familiarity decreases as well. This aspect is confirmed by the related work using humanlike characters, too (cf. Mäkäräinen et al., 2014; Tinwell et al., 2011). Finally, we found a statistically significant interaction effect between all three measures, which means that the factors are interrelated and influence each other when combined. We conclude that using less virtual animal realism atypical features decrease familiarity, which supports H2.

It is possible that the effect appears because of using anthropomorphic facial expressions. Smiling, for example, reduces the familiarity of an animal, but it is a typical human facial expression and does not reflect real animal behavior. For game developers, this means that an animal character should not possess human expressions, emotions, or speech if a realistic animal character should be fully accepted. At lower levels of realism, the difference between neutral depictions and depictions with emotions is not as large as at the difference between both at higher levels of realism. This means that virtual animals rendered at a high level of realism should not deviate from their natural appearance.

In our first study, we found small effects of gender and cat ownership. These results were not confirmed in our second study. We compared the results with the first study and found lower familiarity and aesthetics ratings of female participants towards computer-generated characters at lower degrees of realism (R5-8), which were not used in the second study. These results are in contrast to results by Schwind et al., who showed that female participants rather prefer lower degrees of realism of humanlike avatars than male participants (Schwind et al., 2017). It is conceivable that ratings between male and female participants potentially depend on the kind of species.

6. General discussion

In this paper, we conducted two studies to investigate whether the uncanny valley, originally developed for humanlike characters, applies to virtual animals. The focus of our investigation is to determine whether and when virtual animals, such as used in games, cause negative reactions at certain levels of realism. Our studies concentrate specifically on depictions of cats as they are relatively familiar to humans and frequently used in video games and animated movies.

In our first study, we conducted an online survey to investigate how cats rendered at different levels of realism are perceived. We found a decrease of animal familiarity at intermediate but not at higher rendering realism. Compromised realism manipulation either indicates that the measured construct of realism is potentially affected by other constructs and could be invalid or that stylized and abstract stimuli respectively are part of another construct. Furthermore, the decrease is not as steep as predicted in Mori's graph for humanlike characters. Qualitative feedback from participants judging depictions of cats in current video games supports an uncanny valley of animals and reveals potential causes. We identified three major factors that affect humans' reactions: the violations of the naturalness of the virtual animal, the facial expression, and body pose, as well as how the animal fits into the scene.

Based on our results of the first survey and indications in previous work, we conducted a second study. We investigated the effects of stylization and facial expressions to substantiate further causes for the negative perception of a virtual animal. The results of the second study show that emotions and stylized appearance have a larger effect on familiarity at higher levels of realism compared to lower realism levels. Violations of the expected appearance of an animal cause negative reactions. We assume that our results are potentially caused by the hypothesized uncanny valley by Mori and that previous findings of research investigating this theory can be transferred from humans to depictions of at least one animal (Mori et al., 1970/2012). However, the herein presented study only regards virtual renderings of cats. It is possible that this potentially affects other virtual animals and artificial animals in the real world (e.g.,pet robots, stuffed animals). Furthermore, we point out that the curve of familiarity of animals potentially differs from humanlike characters.

6.1. Theoretical frameworks

In line with Ferrey et al. and Kawabe et al., we suggest to examine an extension of Mori's hypothesis to a broader definition of the uncanny valley by including non-human entities (Ferrey et al., 2015; Kawabe et al., 2016). But how does this new aspect fit into Mori's theory and how can this be explained? The extension of the theory to animals is theoretically applicable to different recent explanations of the uncanny valley: Categorical perception and perceptual mismatch are not explicitly restricted to human likeness.

Difficulties in categorical perception evoke negative responses (Burleigh and Schoenherr, 2015; Burleigh et al., 2013; Cheetham et al., 2011). It is conceivable that our results are caused by negative ratings due to difficulties while discriminating animals and non-animals. In our first study, we found an almost linear relationship for familiarity and realism between the real and computer-generated animal stimuli (R1-6). A high sensitivity towards violations of a known concept (cat) potentially leads to a categorical discrimination between a natural and abstract entity. Visual cues in the abstract category are assessed by individual and aesthetic preferences of the participants. Difficulties in discriminating abstract and real animals might lead to similar negative familiarity ratings as observed for humanlike characters (Burleigh and Schoenherr, 2015; Cheetham et al., 2013; 2011; Ferrey et al., 2015). As previously mentioned, Mori brought multiple categorical entities ("industrial robot", "bunraku puppet") into one continuum of "human likeness". In scope of categorical perception and the uncanny valley, we propose that "human likeness" is not the only continuum that lead to negative responses when brought into relation with related categorical entities (*e.g.*, animals or robots). One example is the previously mentioned "stuffed animal", which is placed into the dimension of "human likeness" in Mori's graph (Fig. 1). A stuffed animal might have humanlike attributes, but can still be classified as "stuffed animal". Categorical perception in scope of the uncanny valley predicts negative responses when an assignment is not clear and an entity has characteristics of two (or more) related constructs as shown for human-animal morphs, for example Ferrey et al. (2015). Difficulties in categorical perception could also explain fears and negative response towards taxidermy animals while trying to distinguish "animal" from "stuffed animal". Thus,

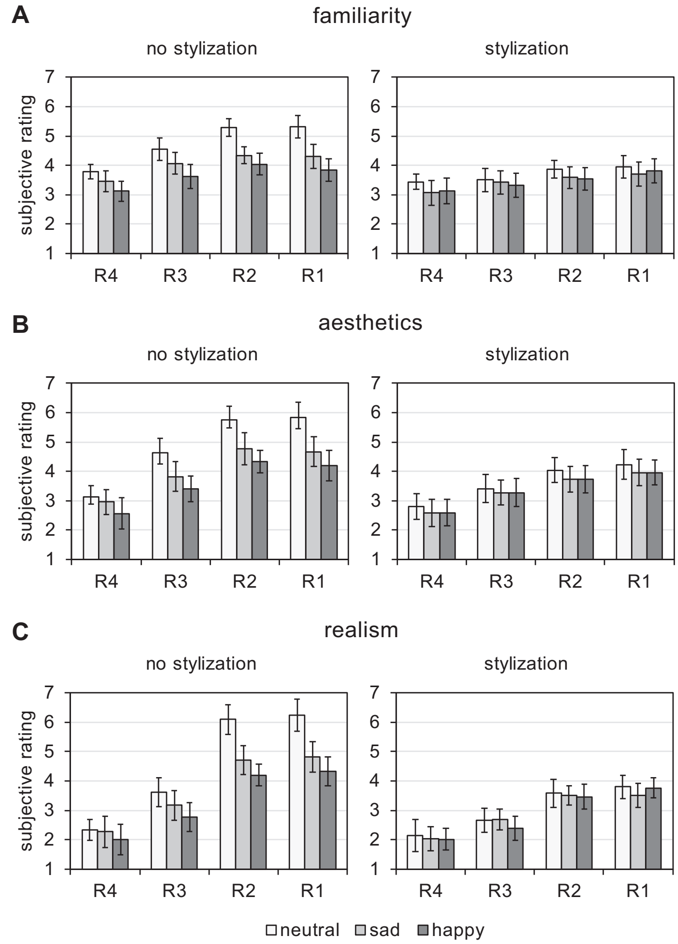


Fig. 5. Perceived familiarity (A), aesthetics (B), and realism (C) for each emotional facial expressions of the cat (neutral, sad, happy), separated by stylization. Error bars show standard deviation (SD).

the uncanny valley would be then be point of lowest familiarity due to difficulties in discriminating ambiguous lifelike entities.

Categorical perception is based on discriminating entities such as human or non-human. However, a humanlike entity is considered as human, even when it contains features that look not "entirely right" (Kätsyri et al., 2015). The perceptual mismatch hypothesis suggests that negative responses are caused by inconsistencies among different realism levels of an entity (not between different categories of entities) (MacDorman et al., 2009; Seyama and Nagayama, 2007). Previous work found that inconsistencies and atypical features increase the effect (MacDorman and Chattopadhyay, 2016; Seyama and Nagayama, 2007). This is supported by our second study, in which decreased realism as well as atypical features of human emotions lead to increased eeriness ratings of a virtual animal. Thus, negative responses due to high sensitivity towards deviations from typical norms and violated expectations could be caused by imperfections of humans *and* animals. This is supported by qualitative feedback in our first study using virtual animals, where missing or wrong features lead to negative responses and unpleasant associations. Our results indicate that using a uniform style (e.g., in R8) in a consistent level of realism lead to positive responses and are potentially responsible for the first peak in Mori's graph.

Researchers assume that the phenomenon has an evolutionary origin (cf. MacDorman, 2005b; Schwind and Jäger, 2016; Steckenfinger and Ghazanfar, 2009). Detecting or avoiding infertile or less fit mates (e.g., Neanderthals MacDorman and Chattopadhyay, 2016; MacDorman et al., 2009) can not be explained by an uncanny valley that includes non-humanoid species. However, our results indicate, that similarly to attractive and youthful characteristics of humans, aesthetic aspects of animals can potentially avoid eerie effects. This could be shown by aesthetic ratings of stimuli R6 in Study 1, where cat depictions with the lowest realism ratings receives significantly higher aesthetic ratings than R5. Aesthetic properties of animals allow conclusions of their well-being. Qualitative feedback in our first study suggests that indicators of threats or infective diseases might partially cause uncanny effects of animals. These aspects have already been proposed as potential explanations for the uncanny valley of humans (MacDorman, 2005b; Schwind and Jäger, 2016). Atypical fur structures, "dead eyes", or threaten poses, might indicate a severe disease such as rabies, which can be transmitted to all warm-blooded species. It is conceivable that the uncanny valley is a cross-species protective mechanism of communicable diseases. This could be supported by previous research that showed reduced eye contact toward less life-like entities in both humans and monkeys (Schwind and Jäger, 2016; Steckenfinger and Ghazanfar, 2009). Such behavior generally reduces further aggressions or provocative responses and helps to prevent potential threats.

We showed that theoretical frameworks such as categorical perception (Burleigh and Schoenherr, 2015; Cheetham et al., 2013; Ferrey et al., 2015; Kawabe et al., 2016) or percpetual mismatch (MacDorman and Chattopadhyay, 2016; MacDorman et al., 2009; Seyama and Nagayama, 2007) of the uncanny valley are potentially applicable and could explain uncanny effects of human and animal entities. When human likeness is not necessarily involved as dimension, there must be an overarching concept that also includes animals (e.g., entity realism or entity category). We suggest that investigating the uncanny valley by consciously considering animals can lead to a better understanding of the phenomenon as a whole.

6.2. Design implications

An uncanny valley of virtual animals would have design implications for animals in games and real-time applications. As our work shows, the realism of animal characters influences how people perceive them. We assume that this also influences the way how people interact with animals in games. An important issue, for example, is the question whether an animal character should have human attributes–such as anthropomorphic characteristics or the ability to speak. This received negative ratings in our second study and is a dilemma for e.g., game developers who want to enable interaction with animals as with humans using speech or facial expressions. For example, players can directly talk and interact with the cat Nibbles in *Witcher III* as with a humanlike character. However, our results show that the positive impression of a realistic animal is lost if it represents something other than itself. Furthermore, enabling interaction between players and virtual animals might negatively affect the acceptance of the virtual animal.

A way out of the valley would be to use high realistic computer-graphics. Our results indicate that native fur geometry and improved shading, correct face, body proportions, and a consonance of environment and animal can improve the visual acceptance in a way that the computer-generated image can hardly be distinguished from a real depiction. Instead of edgy polygon models and flat textures, subdivided and tessellated 3D models using hair physics systems could improve the rendering quality of hair and fur in video games and the acceptance of human observers.

As suggested by Mori, another possibility to avoid potential uncanny effects is to abstract or stylize an animal character (Mori et al., 1970/2012). This is common practice in animated films, for example. Design implications of human- and animal-like 3D characters using stylization are well explored by previous research (Zel et al., 2015; Hyde et al., 2013; McDonnell et al., 2012). We assume that the art of stylization is well-established due to technical limitations that make it hard for designers to create artificial animals that cannot be distinguished from real animals anymore. Imperfect replicas of animals potentially cause negative feelings resulting from the uncanny valley. In our study, an abstract black and white representation caused more positive associations than current video game graphics. Furthermore, the overall impression of a virtual animal should not violate the expected nature of a real one and should not have attributes or behavior which may be considered as abnormal or threatening. In contrast, the eeriness of a virtual animal can deliberately be used to create tension or fear in horror games, for example.

6.3. Limitation and future work

One limitation of the herein presented work is that our measures do not differentiate the feeling of *uncanniness* from other feelings such as fear, disgust, or horror. Even the qualitative feedback does not provide more detailed insights into the notion of *the uncanny* (and other negative feelings) and should be regarded by future work. Furthermore, this paper focuses on investigating the uncanny valley using depictions of only one animal species, namely cats. We only assume that our findings are also valid for other animal species and suggest future research to explore further animals. However, there are complex interactions between humans and domesticated animals, which are not currently not regarded. This is also one limitation of the herein presented study as only one domesticated pet species (cat) has been considered. Breeding, for example, has changed the appearance of animals to make those breeds more appealing to humans. This could be considered in further studies comparing different kinds of animals and breeds. Here, a direct comparison between familiar (e.g., pets) and rather unknown animal species could be investigated as well. Future work should also pay attention to familiarity and positive associations of individual prejudices against certain animals. Studies on discriminating humans and animals indicate that there are different thresholds for categorization human from non-human and animal from non-animal entities (Burleigh and Schoenherr, 2015; Campbell et al., 1997). This should be considered in developing questionnaires aiming to quantify human- *and* animal-likeness with respect to the uncanny valley.

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